PR

3590

JPRS: 3590

22 July 1960

SIMPLIFIED METHOD OF THERMAL CALCULATION FOR A REACTOR USING PRESSURIZED WATER

- USSR -

By L. N. Muchnik

Distributed by:

OFFICE OF TECHNICAL SERVICES
DEPARTMENT OF COMMERCE
WASHINGTON 25, D. C.
~~Price: $0.50~~

U. S. JOINT PUBLICATIONS RESEARCH SERVICE
205 EAST 42nd STREET, SUITE 300
NEW YORK 17, N. Y.

F O R E W O R D

This publication was prepared under contract by the UNITED STATES JOINT PUBLICATIONS RESEARCH SERVICE, a federal government organization established to service the translation and research needs of the various government departments.

JPRS: 3590

CSO: 3631-D

SIMPLIFIED METHOD OF THERMAL CALCULATION FOR A REACTOR USING PRESSURIZED WATER

[Following is a translation of an article by L. N. Muchnik in the Russian-language periodical Inzhnerno-fizicheskiy zhurnal (Journal of Engineering Physics), Minsk, Vol. 2, No. 12, December 1959, pages 105-109]

The thermal calcualtions of nuclear reactors cooled by pressurized water can be simplified by using nomograms made up from the graphical dependence between the quantities characterizing the construction of the reactive zone and the parameters of heat conductivity. The method of constructing such nomograms is presented below, together with the method of using them. The application of the nomograms is very convenient for carrying out variance calculations.

It is assumed that the active zone of the reactor is practically a cylinder. The thermal transfer has an extremely high value of q_{max} in Kcal/m^2/hr at the center of the reactor. With sufficient accuracy we may assume that along the axis of the reactor the heat conduction varies as the cosine [1]. Then the temperature of the water at the center of the reactor is

$$tc = tex - \sqrt{\left(\frac{\Delta t_{\Sigma}}{2}\right)^2 + \left(\frac{q_{max}}{\alpha}\right)} \qquad (1)$$

By this expression one can calculate the deviation at a point between the center of the reactive zone and the outlet of the reactor. The wall temperature of the heat-conducting element has a very large value equal to t_{ex}. In this formula we have the amount of heating of water in the central channels of the reactor Δt_c and the heat-exchange coefficient α from the wall of the thermal conductor to the water.

The quantities q_{max} and α can be expressed as follows [1,2]:

$$q_{max} = q\, k_q, \qquad (2)$$

$$\alpha = 0{,}021 \frac{\lambda}{d_H} \left(\frac{W_{max} d_H \rho}{\mu} \right)^{0{,}8} Pr^{0{,}43} \varphi, \qquad (3)$$

where q is the mean heat transfer of the thermally conducting elements in $Kcal/m^2/hr$; k_q is the coefficient of nonuniformity of thermal conductivity in the reactor; d_H is the hydraulic diameter of the channels of the heat conductor in meters; W_{max} is the velocity of the water at the center of the reactor in m/sec. The thermal resistance λ, the viscosity μ, the density ρ, and the Prandtl number Pr depend on the pressure and temperature of the water at the center of the reactor and the quantity

$$\varphi = \left(\frac{Pr}{Pr_w} \right)^{0{,}25}$$

which is close to unity. (Pr_w is the Prandtl number for water at a temperature equal to the wall temperature of a thermally conducting element at the center of the reactor.)

Taking into account the coefficient of nonuniformity in the distribution of velocities of the water along a radius of the reactor, kw, we can write

$$W_{max} = Wk_w,$$

Where W is the mean velocity of water in the reactive zone in m/sec. The quantity W can be expressed by the volume discharge of water V (m^3/hr); and, by using the heat-balance equation, by the thermal power of the reactor Q (Kcal/hr). Then for a single-pass reactor with a channel cross section F in m^2 we obtain the relationship

$$W_{max} = \frac{V}{3600F} k_w = \frac{Qk_w}{3600 C_p \rho g F \Delta t}, \qquad (4)$$

where C_p and ρ are the heat capacity ($Kcal/Kg^oC$) and the density ($kg/sec^2/m^4$) respectively of water at the center of the reactor; Δt is the total heating of water in the reactor.

Putting the value obtained for W_{max} in equation (3) and using the relations (2) and (3), we obtain the following formula where

$$\frac{q_{max}}{\varphi} = 20{,}7 \cdot 10^4 F_Q F_{pt} \Delta t^{0{,}8},$$

where

$$F_{pt} = \frac{(\mu C_p)^{0{,}8}}{\lambda \, Pr^{0{,}43}} \qquad (5)$$

is a complex quantity depending only on the pressure and temperature of the water at the center of the reactor;

$$F_Q = \frac{d_H^{0,2}\, F^{0,8} q}{Q^{0,8}\, \varphi}\;\frac{\mu_q}{k_w^{0,8}} = \frac{d_H^{0,2} F^{0,8} Q^{0,2}}{S\, \varphi}\;\frac{\mu_q}{k_w^{0,8}} \qquad (6)$$

is a comples quantity depending only on the construction of the reactive zone and the thermal power of the reactor; and S designates the total surface through which heat flows in m^2.

In the case where there are two or more consecutive concentric thermally conducting paths in the reactive zone, the mean velocity of the water for the whole reactive zone is

$$w = \frac{V}{3600\, F_{av}}$$

where $F_{av} = F/N$ is the mean channel cross section of one path divided by the total number of paths N. Therefore F_Q is defined here by the following formula

$$F_Q = \frac{d_H^{0,2}\, Fav^{0,8}\, Q^{0,2}}{S\, \varphi}\;\frac{kg}{Kav^{0,8}}\left(\frac{Kcal}{m\text{-}hr}\right)^{0,2} \qquad (6.a)$$

Putting the expression q_{max}/α in (1), we obtain the following formula

$$tc = tex - \sqrt{\left(\frac{\Delta t}{2}\right)^2 + 13\cdot 10^4\, F_Q^2\, F_{pt}^2 \left(\frac{\Delta t}{2}\right)^{1,6}} \qquad (7)$$

For convenience in using the relation (7), a nomogram was constructed with the coordinate axes Δt - t_c (Fig. 1). The nomogram includes three families of curves corresponding to a water pressure in the reactor of 100, 150, and 200 atm. The solid curves characterize the working region of reactors at constant values of F_Q (from 0.04 to 0.10). The broken-line curves correspond to the constant values of the ratio V/Q (from $40\cdot 10^{-6}$) and characterize the quantity of outflow of water in the reactive zone. They are calculated from the formula

$$\Delta t = \frac{\gamma}{Cp}\;\frac{1}{V/Q}$$

where v is the specific volume of water at the center of the reactor.

For the maximum wall temperature of the thermally conducting element, tex, we take the saturation temperature at the corresponding water pressure, which is a specific temperature below which there is no possibility of boiling on the surface of the thermally conducting elements. In order to get the necessary heating to the saturation temperature, we must compute a correction to the quantity t_c taken from the momogram.

In the construction of the nomogram the assumption is made that the water heating in the central channels Δtc is equal to the total heating of water in the reactor Δt. It is based on the fact that the quantity $\left(\frac{\Delta tc}{z}\right)^2$ occuring in formula (1) is usually negligible with respect to the quantity $\left(\frac{q_{max}}{\alpha}\right)^2$

As can be seen from the nomogram, the combination of variables F_Q is an important thermal characteristic of the reactor, which fortunately converges to result in low values of F_Q. As can be seen from formula (6,a.), F_Q can be lowered at a given thermal power of the reactor by decreasing the hydraulic diameter and the channel cross section of the heat conductors, and also by increasing the heat-exchange surface, i.e., by lowering the heat transfer.

There is a definite effect on the magnitude of F_Q if the non-uniformity of heat conduction k_q is decreased, or if the coefficient of nonuniformity in the velocity of water k_w is increased. However, the quantity $k_w^{0.8}$ cannot exceed the coefficient of nonuniformity in heat conduction along the radius of the reactor, otherwise the peripheral channels would be under greater thermal stresses than the central ones.

We shall give one of the possible ways of using the nomogram for thermal calculation. It is required to determine the pressure p at which there is no possibility that boiling can occur on the surface of the thermally conducting elements with underheating to 15° below the saturation temperature. The reactor is a single-path one with a thermal power equal to $60 \cdot 10^6$ Kcal/hr.

We assume that a choice of construction of the reactive zone has been made, that the dimensions have been fixed, and that, proceeding from this, the thermal characteristic of the reactor F_Q came out to be 0.07 $(\text{Kcal/m/hr})^{0.2}$. Proceeding from the given parameters of the vapor on a secondary contour, the mean temperature of water in the water in the reactor cannot be less than $t_c = 282°$ C. The outflow of water on a primary contour V, which depends on the power of the circulating pumps, is equal to 4,200 m^3/hr.

1. $$\frac{V}{Q} = \frac{4200}{60 \cdot 10^6} = 70 \cdot 10^6 \text{ m}^3/\text{kcal}$$

2. The maximum attainable temperature of water at the center of the reactor (according to the nomogram):

$$t_c = 276.5^oC \text{ at } 100 \text{ at atm,}$$

$$t_c = 306.5^oC \text{ at } 150 \text{ at atm.}$$

3. Heating of water in the reactor (according to the nomogram):

$$\Delta t = 15.3^oC \text{ at } 100 \text{ atm,}$$
$$\Delta t = 14.9^oC \text{ at } 150 \text{ atm.}$$

At the roquired pressure

$$\Delta t = 15.3 - \frac{282 - 276.5}{306.5 - 276.5}(15.3-14.9)=15.23^oC$$

(determined by linear interpolation).

5. The corresponding minimum attainable water pressure in the reactor (according to tabulated data) is equal to 108 atm. With underheating of the wall to about 15° below the saturation temperature, the pressure required in the reactor (with a saturation pressure of about 330°C)

$$p = 132 \text{ atm.}$$

6. Checking by formula (7):
at 132 atm and 282° C

$F_{pt} = 2.52 \cdot 10^{-4}$ (determined from the nomogram of Fig. 2)

$$F_Q = 0.07,$$

$$t_c = 315.2 - \left[\left(\frac{15.23}{2}\right)^2 + 13 \cdot 10^{10} \cdot 0.07^2 \times \right.$$

$$\left. \times (2.521 \cdot 10^{-4}) \left(\frac{15.23}{2}\right)^{1,6}\right]^{1/2} = 315.2-33.3 = 281.9^o \text{ C.}$$

The value obtainod corresponds with sufficiont accuracy to the requirod value of $t_c = 282^o$ C.

BIBLIOGRAPHY

1. Skvortsov, S.A. Vodo-vodyanyye energeticheskiye reaktory (VVER) v SSSR /Water and Aqueous Energy Reactors in the USSR/. A report presented at the Second International Conference on Peaceful Uses of Atomic Energy. Geneva, 1958.

2. Mikheyev, M. A. Osnovy teploperedachi /Fundamentals of Heat Transfer/. Gosenergoizdat, 1956.

3. Handbook Teplofizicheskiye svoystva veshchestv /Thermophysical Properties of Materials/. Editor: N. B. Varagaftik. Gosenergoizdat, 1956.

FIGURE APPENDIX

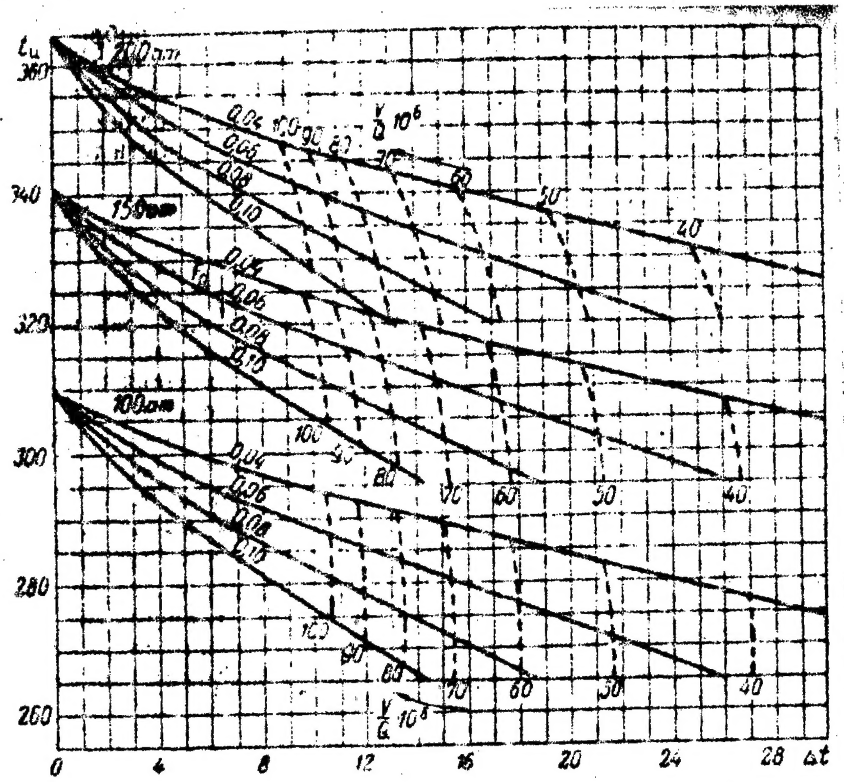

Fig. 1. Nomogram for thermal calculation for a reactor cooled by pressurized water.

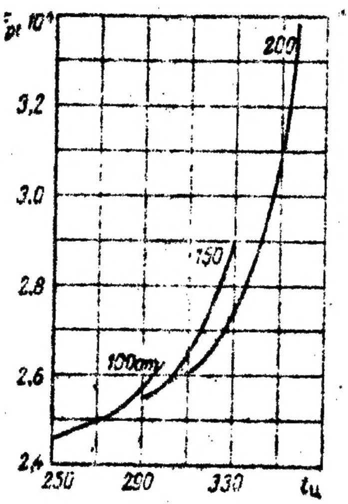

Fig. 2. Nomogram for the determination of F_{pt}.

5571

- END -